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Solar energy in Malaysia: Current state and prospects

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ABSTRACT

Malaysia is situated at the equatorial region with an average solar radiation of 400–600 MJ/m^2 per month. It has a promising potential to establish large scale solar power installations; however, solar energy is still at the infancy stage due to the high cost of photovoltaic (PV) cells and solar electricity tariff rate. The Malaysian government is keen to develop solar energy as one of the significant sources of energy in the country. According to the 9th Malaysia Plan (9MP), a large allocation had been dedicated for implementation of solar PV systems. On 25th July 2005, a Malaysian Building Integrated Photovoltaic (MBIPV) project had been announced and it was planned to end by 2010. The project consists of three categories which include: BIPV demonstration, national "SURIA1000" and BIPV showcase. Greater emphasis will be placed on energy efficiency under the Tenth Malaysia Plan (2011–2015). This paper discusses present and future situation of solar power in Malaysia, utilization of solar energy and the strategies taken by the Malaysian government and Non-Government Organizations (NGOs) to promote solar energy thermal applications and electricity power generation in the future.

Contents

1. Introduction

The era of generating electric power in very large steam-powered central stations seems to have ended. The increased concerns for environmental impacts of conventional fossil fuels, most importantly those related to climate change, has been the main factor driving the transition towards green energy and generation of power most favourably from renewable energy sources that are abundant and free [1]. Governments and industries all around the world are increasingly looking for ways to reduce the greenhouse emissions from their operations with a major focus on the use and installation of sustainable renewable energy systems [2]. Solar energy is the most promising backup energy as it has many advantages over other resources. Solar energy is a naturally available and clean energy source derived from the sun that can be exploited directly to generate electricity [3]. No release of pollutant,

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Nomenclature

PV	photovoltaic
NGOs	Non-Government Organizations
FDP	Fuel Diversification Policy
NFPE	Non-Financial Public Enterprises
GDP	Gross Domestic Product
TNB	Tenaga Nasional Berhad
SESB	Sabah Electricity Sdn. Bhd.
SESCO	Sarawak Energy Supply Corporation
PTM	Pusat Tenaga Malaysia (Malaysia Energy Centre)
MEGTW	Ministry of Energy, Green Technology and Water
UNITEN	University Tenaga Nasional
TNR	Tenaga National Research
KESAS	Konsortium Expressway Shah Alam Selangor Sdn. Bhd.
BP	British Petroleum
UKM	University Kebangsaan Malaysia
BIPV	Building Integrated Photovoltaic
PSH	Prototype Solar House
IGS	Industry Research and Development Grant Scheme
NLCC architect	An architect firm
ISE	Institute of Solar Energy
SWHs	Solar Water Heaters
LPG	Liquefied Petroleum Gas
EWHs	Electric Water Heaters
RE	renewable energy
MBIPV	Malaysian Building Integrated Photovoltaic
MP	Malaysia Plan
PVMC	Photovoltaic Monitoring Schemes
UiTM	University Technology MARA
CETDEM	Centre for Environment, Technology and Development Malaysia
ZEO	Zero Energy Office
HQ	Headquarter
IEA-PVPS	International Energy Agency-Photovoltaic Power Systems
CIS	Copper-Indium-Diselenide
EPU	Economic Planning Unit
NPC	National Planning Council
NPAC	National Petroleum Advisory Council
FIC	Foreign Investment Committee
NDPC	National Development Planning Committee
MECM	Ministry of Energy, Communications and Multimedia Malaysia
MEWC	Ministry of Energy, Water and Communication
EC	Energy Commission
GoM	Government of Malaysia
MoSTE	Ministry of Science, Technology and Environment
IRPA	Intensification of Research in Priority Areas
R&D	Research and Development
MoRD	Ministry of Rural Development
MoE	Ministry of Education
USM	University Science Malaysia
UPM	University Pertanian Malaysia
UM	University Malaya
UTM	University Technology Malaysia
DoE	Department of Environment
EIA	Environmental Impact Assessment
IPPs	Independent Power Producers
CAP	Consumer Association of Penang
MOSTI	Ministry of Science, Technology and Industry
STC	Standard Test Conditions
MDG	Millennium Development Goals
ICT	Information and Communication Technology
BDD	Bridging Digital Divide
VSAT	Very Small Aperture Terminal
TNBES	TNB-Energy Services Sdn. Bhd.
SREP	Small Renewable Energy Programme
FiTs	feed-in tariffs
EEG	Erneuerbare-Energien-Gesetz
RM	Ringgit Malaysia

Subscripts

Ktons	kilotons
°	degrees
sq km	square kilometre
%	percentage
mm	millimetre
°C	degrees celsius
°F	degrees fahrenheit
MJ/m^2	mega joule per meter square
GWh	gig watt hour
kWh/m^2	kilowatt hour per meter square
kWp	kilowatt peak
MWp	megawatt peak
kW	kilowatt
MW	megawatt
$kWh/m^2/yr$	kilowatt hour per meter square per year
H	efficiency

low maintenance and high reliability, with life span expectation of 20–30 years made solar power a favourable source of energy to be used in the future [4]. There are enormous applications of photovoltaic technology such as solar water heating, solar drying and solar PV; however, solar applications were first introduced for rural electrification and telecommunication [5,6].

2. Geographic profile of Malaysia

Malaysia is positioned on the South China Sea and lies between 1° and 7° in North latitude and 100° and 120° in East longitude [7]. Malaysia is crescent-shaped which consist of Peninsular Malaysia (West Malaysia) and states on the island of Borneo, namely Sabah and Sarawak (East Malaysia). The total land area is about 330,000 sq km of which almost 60% is made up of East Malaysia and the balance of 40% made up by the Peninsular Malaysia. The majority of the population is concentrated in Peninsular Malaysia comprising about 76% of the total population. In 2010, the birth rate is reported 22.0/1000 with a growth rate of 1.7% while the infant mortality rate is 15.3/1000. Life expectancy increased to 73.5 while the density is 76 per sq km [8].

The monsoon winds occur twice in a year. There are two types of monsoon, namely Northeast monsoon and Southwest monsoon. Northeast monsoon occurs when the wind blows from central Asia to South China Sea through Malaysia and move on to Australia between November and March. Meanwhile, the Southwest monsoon occurs when the wind blows from Australia across the Sumatra Island and move to the Strait of Malacca between May and September. Winter-monsoon occurs during April and October and between September and December. West Malaysia experiences the more heavy rainfall with the measurement of 2500 mm per year, whereas in East Malaysia it is approximately 5080 mm per year with the load usually focus on October until February [7,8].

Malaysia's climate has relatively high levels of temperature and humidity. The humidity varies from 80% to 90% except for highlands. Throughout the year, the temperature ranges between

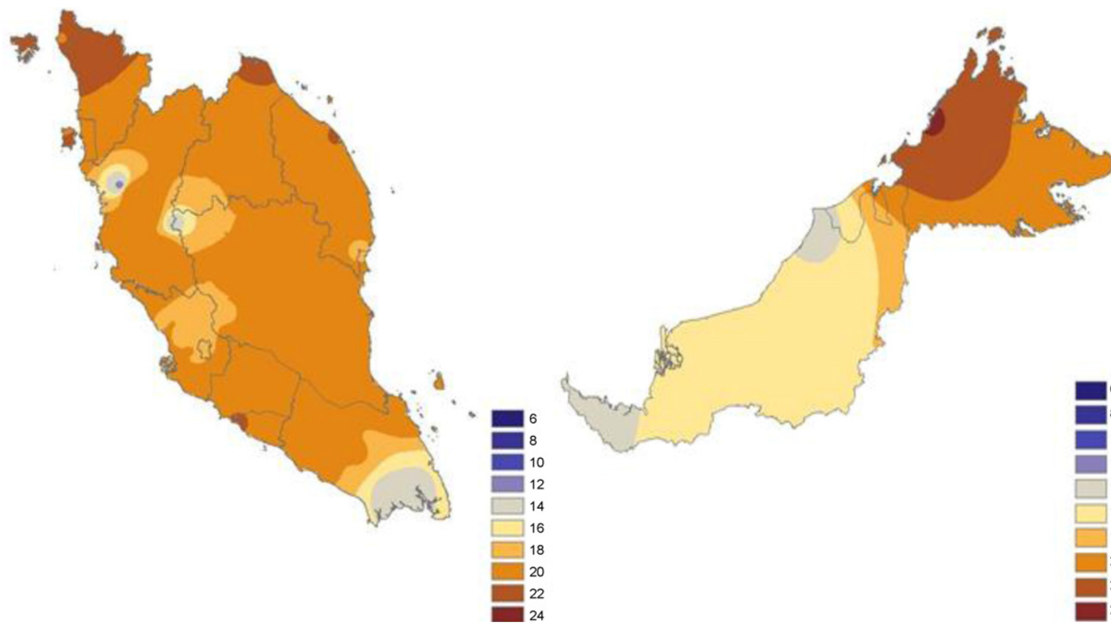


Fig. 1. Annual average solar radiation (MJ/m^2/day).

22 °C and 33 °C (72–91 °F) and the average daily temperature is 26.5 °C.

The monthly solar radiation in Malaysia is approximately around 400–600 MJ/m^2. It goes higher during the Northeast monsoon period and lowers during the Southwest monsoon [7,8]. Fig. 1 shows the annual average of solar radiation (MJ/m^2/day) in Malaysia.

3. Current energy situation in Malaysia

Currently, Malaysia is adopting the 5th Fuel Diversification Policy (FDP) which was introduced in 1999 [9]. The introduction of FDP was to reduce Malaysia's over-reliance on a specific fuel type and to achieve a more balanced supply mix between natural gas, oil, coal and hydropower. The country is embarking on a gradual change for fuel consumption from depending solely on one specific source of energy to a mix of fuel sources derived from hydropower and coal [10]. Based on the 9th Malaysia Plan (2000–2010), the use of oil, gas and hydro had declined from 4.2% to 0.2%, from 77% to 55.9% and from 10% to 5.6%, respectively; however, the hydro power generation increased for Sabah and Sarawak from 21.3% (in 2000) to 26.5% (in 2010) and from 14.3% (in 2000) to 31.7% (in 2010), respectively. On the other hand, power generation from coal rose drastically from 8.8% to 36.5%. Table 1 indicates the government's strategy to reduce its over-reliance from oil and gas to coal and hydro power is achievable on a gradual basis.

In the 8th Malaysian plan, the expenditure of RM 76.2 billion by Federal Government and Non-Financial Public Enterprises (NFPEs) was paid out for energy sector programmes, as shown in Table 2. Also, the expenditure of the electricity supply as well as oil and gas industries amounted to RM 27.9 billion and RM 48.3 billion, respectively. For the Ninth Plan period, RM 1.8 billion is allocated for development of the energy sector while the investment expenditure by the NFPEs will total RM 71.7 billion [11].

3.1. Population distribution

According to the Department of Statistics, Malaysian population has risen from 27.17 million in 2007 to 28.31 million in 2009. Besides, various age structure groups have different impact on the economy of the country. Younger generation group lifestyle would differ from those ages 65 years and above; however, increase in population for both age groups would result in a corresponding increase in energy consumption. Population in Malaysia and the population by age group are shown in Figs. 2 and 3 respectively.

3.2. Energy consumption and demand

Preliminary Energy Outlook released by Malaysia Energy Centre (PTM) has predicted 5% increase per annum in Gross Domestic Product (GDP), while Malaysia's final energy consumption is expected to grow at an annual rate of 4.8% from 2000 to 2030. For the next 25 years, annual increase in the transportation, industry and other sectors such as residential, commercial and agricultural sectors will rise 5.3%, 4.8% and 4.2%, respectively. Energy demand in the term of fuel type will increase significantly; gas will increase

Table 1
Fuel mix in electricity generation, 2000–2010.

Year	Oil	Coal	Gas	Hydro	Others	Total (GWh)
	% of total					
Malaysia						
2000	4.2	8.8	77.0	10.0	0.0	69,280
2005	2.2	21.8	70.2	5.5	0.3	94,299
2010	0.2	36.5	55.9	5.6	1.8	137,909
TNB						
2000	2.3	8.7	79.6	9.4	0.0	63,634
2005	0.5	22.5	71.9	4.9	0.2	86,242,
2010	0.1	38.1	56.8	3.4	1.6	126,718
SESB						
2000	47.3	–	31.4	21.3	–	2299
2005	42.6	–	43.0	13.6	0.8	3447
2010	0.5	18.5	47.2	26.5	7.3	4808
SESCO						
2000	11.2	15.1	59.4	14.3	–	3347
2005	4.7	25.0	58.9	11.4	–	4610
2010	3.0	21.2	44.1	31.7	–	6383

Source: 9th Malaysian Plan, Tenaga Nasional Berhad, Sabah Electricity Sdn. Bhd. and Syarkat SESCO Berhad [10].

Table 2
Development expenditure and allocation/investment for energy sector programmes, 2000–2010 (RM million).

Program	8MP expenditure			9MP allocation		
	Federal Government	NFPEs[a]	Total	Federal Government	NFPEs	Total
Electricity	2386.90	25,574.00	27,960.90	1828.80	27,955.10	29,783.90
Generation	664.00	12,138.70	12,802.70	–	9506.60	9506.60
Transmission	632.50	5121.40	5753.90	302.60	6781.90	7084.50
Distribution	357.00	8313.90	8670.90	334.00	11,666.60	12,000.60
Rural electrification	560.20	–	560.20	1025.30	–	1025.30
Others	173.20	–	173.20	166.90	–	166.90
Oil and gas	–	48,300.00	48,300.00	–	43,800.0	43,800.00
Upstream	–	16,700.00	16,700.00	–	13,100.00	13,100.00
Downstream	–	31,600.00	31,600.00	–	30,700.00	30,700.00
Total	2386.90	73,874.00	76,260.90	1828.80	71,755.10	73,583.90

Source: Economic Planning Unit.
[a] Refers to Tenaga Nasional Berhad, Sabah Electricity Sdn. Bhd., Syarikat SESCO Berhad and Petroliam Nasional Berhad.

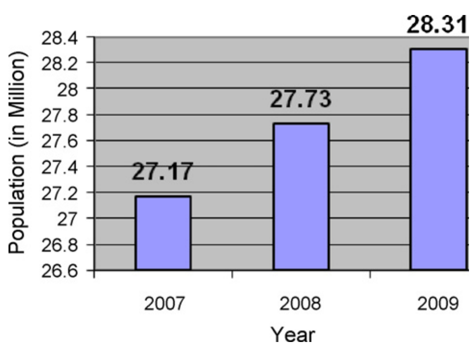


Fig. 2. Population in Malaysia between 2007 and 2009 [10].

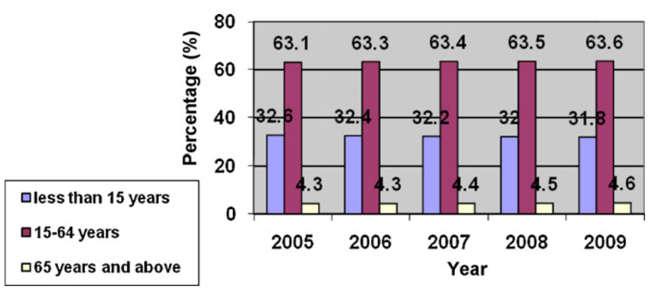


Fig. 3. Population by age group [10].

6.3% per annum for the industrial sector. Electricity will increase 5.3% while oil will remain the most used fuel with 4.7% per annum. Coal and other fuels demand will rise 2.8% and 1.5%, correspondingly [12].

Tables 3 and 4 are the primary commercial energy supply and final commercial energy demand respectively by source between 2000 and 2010, while the peak demand for energy and accumulated installed capacity with reserve margin is shown in Table 5. From Table 4, it can be concluded that peak demand has been doubled from 10,657 MW in 2000 to 20,087 MW in 2010. Similarly, the accumulated installed capacity also has risen from 14,291 MW to 25,258 MW in the same period.

Increasing trend of the electricity energy demand and capacity in Peninsular Malaysia is further emphasized in a forecast released by the Energy Commission 2006 (Fig. 1); however, it predicts a decreasing trend in electricity growth rate against the energy demand between 2007 and 2011 [13] (see Fig. 4).

3.3. Renewable energy policies in Malaysia

The key Malaysian government ministries and agencies involved in energy efficiency improvement are the Energy Unit of Economic Planning Unit (EPU) of the Prime Minister's Office, the Ministry of Energy, Green Technology and Water (MEGTW), the Energy Commission (EC) and Pusat Tenaga Malaysia (PTM) or the Malaysia Energy Centre. All agencies perform their duties for the central government [14,15].

Economic Planning Unit (EPU) plays an important role in planning and formulating policies for development of renewable energy (RE) projects in Malaysia. The EPU acts as a secretariat to the National Planning Council (NPC), the National Petroleum Advisory Council (NPAC), Foreign Investment Committee (FIC), National Development Planning Committee (NDPC) and other inter-departmental economic development planning committees [16,17].

Ministry of Energy, Green Technology and Water (MEGTW) is to formulate energy efficiency policy, in coordination with the EPU. MEGTW was founded in April 2009 following the reshuffle of the Malaysian Cabinet. It was formerly known as the Ministry of Energy, Water and Communications in 2004 and the Ministry of Energy, Communications & Multimedia in 1998 [4].

The Energy Commission (EC) is responsible for regulating gas retailers. It was first established in 2001, replacing the Department of Electricity and Gas Supply (DEGS). The Commission's main tasks involve providing technical and performance regulation for the

Table 3
Primary commercial energy supply[a] by source, 2000–2010.

Source	Petajoules			% of total			Average annual growth rate (%)	
	2000	2005	2010	2000	2005	2010	8MP	9MP
Crude oil and petroleum products	988.1	1181.2	1400.0	49.3	46.8	44.7	3.6	3.5
Natural gas[b]	845.6	1043.9	1300.0	42.2	41.3	41.6	4.3	4.5
Coal and coke	104.1	230.0	350.0	5.2	9.1	11.2	17.2	8.8
Hydro	65.3	71.0	77.7	3.3	2.8	2.5	1.7	1.8
Total	2003.1	2526.1	3127.7	100.0	100.0	100.0	4.7	4.4

Source: Ministry of Energy, Water and Communications and Economic Planning Unit.
[a] Refers to the supply of commercial energy that has not undergone a transformation process to produce energy.
[b] Excludes flared gas, re-injected gas and exports of liquefied natural gas.

Table 4
Final commercial energy demand by source,[a] 2000–2010.

Source	Petajoules[b]			% of total			Average annual growth rate (%)	
	2000	2005	2010	2000	2005	2010	8MP	9MP
Petroleum products	820.0	1,023.0	1,372.9	65.9	62.7	61.9	4.5	6.1
Natural gas[c]	161.8	246.6	350.0	13.0	15.1	15.8	8.8	7.3
Electricity	220.4	310.0	420.0	17.7	19.0	18.9	7.1	6.3
Coal and coke	41.5	52.0	75.0	3.4	3.2	3.4	4.6	7.6
Total	1243.7	1631.7	2217.9	100.0	100.0	100.0	5.6	6.3
Per capita consumption (gigajoules)	52.9	62.2	76.5				3.3	4.2

Source: Ministry of Energy, Water and Communications and Economic Planning Unit.
[a] Refers to the quantity of commercial energy delivered to final consumers but excludes gas, coal and fuel oil used in electricity generation.
[b] Joule is the unit of energy to establish the equivalent physical heat content of each energy form. One megajoule = 106 joules, one gigajoule (GJ) = 109 joules and one Petajoule (PJ) = 1015 joules. One PJ = 0.0239 million tons of oil equivalent (mtoe). One toe = 7.6 barrels.
[c] Includes natural gas used as fuel and feedstock consumed by the non-electricity sector.

Table 5
Installed capacity (peak demand and reserve margin), 2000–2010.

Year	Generation by system[a]	Accumulated installed capacity	Peak demand[b] (MW)	Reserve margin[b] (%)
2000	TNB	12,645	9712	30.2
	SESB	785	391	100.8
	SESCO	861	554	55.4
	Total	14,291	10,657	34.1
2005	TNB	17,622	12,493	41.1
	SESB	639	543	17.7
	SESCO	954	743	28.7
	Total	19,217	13,779	39.5
2010	TNB	22,802	18,187	25.4
	SESB	1100	802	37.2
	SESCO	1356	1098	23.5
	Total	25,258	20,087	25.7

Source: Tenaga Nasional Berhad, Sabah Electricity Sdn. Bhd. and Syarikat SESCO Berhad.
[a] System refers to utilities and the respective IPPs.
[b] Peak demand is the maximum power demand registered by the system in a stated period of time.
[c]Reserve margin equals accumulated capacity minus peak demand, all of which divided by peak demand and multiplied by 100.
[d]Including supply from the Bakun Hydroelectric Project.

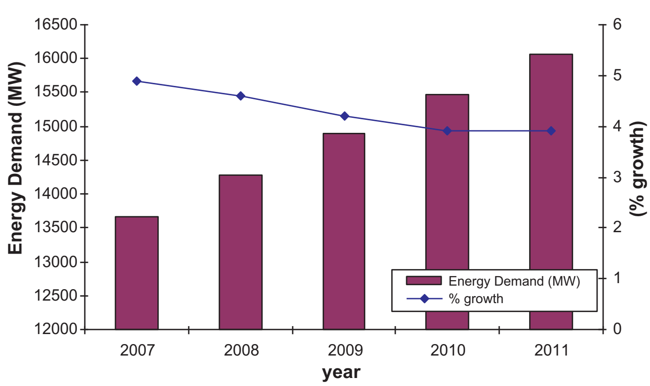


Fig. 4. Electricity demand forecast (Energy Commission, 2006).

electricity and piped gas supply industry, as the safety regulator for electricity and piped gas and give consultations on electricity and piped gas supply including energy efficiency and renewable energy issues to the ministry [2,7].

Malaysia Energy Centre (PTM) is the main agency for all kinds of the government's energy efficiency and RE projects. PTM was established in 1997 as a Non-Governmental Organisation (NGO) to carry out energy studies and performing energy analysis (including developing and maintaining a comprehensive national energy database).

Ministry of Science, Technology and Innovation (MOSTI) was established in 1973 as the Ministry of Technology, Research and Local Government; however, with the growth of national imperatives it was invested with additional responsibilities as the lead agency on environmental matters and reassigned as the Ministry of Science, Technology and Environment (MOSTE) in 1976. In 27 March 2004, MOSTE was restructured and the Ministry of Science, Technology and Innovation (MOSTI) was founded. MOSTI is in charge of research, telecommunication and information technology [18].

Moreover, the Ministry of Information, Communication and Culture (KPKK) has publicised RE through the mass media while the Ministry of Rural Development (MoRD) is involved in planning, formulation, implementation and evaluation of programmes and strategies for rural development, including electricity. In addition to these coordinated effort by various bodies, the MoRD oversees the planning, co-ordination and implementation of the rural electrification programme [17]. During the 9th Malaysia Plan (MP), there was an improvement in electricity supply to rural areas which benefited 59,960 housing units mainly in Sabah and Sarawak, as shown in Table 6 [11].

Table 6
Rural electrification coverage[a] by region, 2000–2010 (%).

Region	2000[b]	2005	2010
Peninsular Malaysia	97.5	98.6	98.8
Sabah	67.1	72.8	80.6
Sarawak	66.9	80.8	89.6
Malaysia	89.5	92.9	95.1

Source: Economic Planning Unit and Ministry of Rural and Regional Development.
[a] This refers to rural housing units served as a percentage of total rural housing units.
[b] This refers to Census 2000 data excluding housing units served with private individual generators.

Ministry of Education (MoE) has been vigorously promoting RE for the curriculum activities and course content for schools, colleges and universities in Malaysia, especially on energy and RE curricular activities in science and engineering subjects [17]. For Malaysian R&D activities, most of the universities and research institutions have been conducting fundamental and applied research in the energy field. University Science Malaysia (USM) has undertaken training and research in renewable energy and energy efficiency. University Kebangsaan Malaysia (UKM) research activities are on solar thermal systems, solar cells fabrications and characterization, off grid and grid connected photovoltaic (PV) hybrid systems and PV system components; while at University Pertanian Malaysia (UPM), research is on solar energy and biomass. In University of Malaya (UM), the research is focused on Building Integrated Photovoltaic (BIPV) under Malaysian climate, energy conservation in industries and alternative fuels, while in University Technology Malaysia (UTM), the research is on energy conservation in buildings and industries, cogeneration and alternative fuels [14,17].

In the case of environmental matters, the controlling, monitoring, conserving and maintenance is undertaken by the Department of Environment (DoE). Environment Quality Act, 1974, was the first legislation developed for the purpose of environmental conservation. This is followed by a number of other legislations, regulations and guidelines. The DoE has issued the Environmental Impact Assessment (EIA) Order in 1987 which listed a set of guidelines for Environmental Impact Assessment to ensure the better understanding of the government's requirements in relation to the environment for all affected projects, including power projects [15,17].

Meanwhile, for the electricity industry field, Tenaga Nasional Berhad (TNB), Sabah Electricity Sdn. Bhd. (SESB) and Syarikat SESCO Bhd. (which was formerly known as Sarawak Energy Supply Corporation (SESCO)), are responsible for regulating the supply of electricity. These three agencies are involved in conducting the demand forecast and responsible for supply planning for the future. Although there is a large number of Independent Power Producers (IPPs) which had entered the power market, however, TNB still holds a monopoly on power transmission and distribution for Peninsular Malaysia, whereas SESB and SESCO hold monopolies in Sabah and Sarawak, respectively [17,19]. Currently the largest power station in Malaysia is the Sultan Ismail power station in Paka, Terengganu, which is owned by TNB and powered by oil and gas [17]. Consumer Association of Penang (CAP) has supported RE by promoting it throughout this country. However, the lack of governmental energy policy and funds had limited this association's activities.

3.4. Solar energy resources distribution in Malaysia

Malaysia is ideal for large scale solar power installations due to its location in the equatorial region. Table 7 is a summary of yearly average solar radiation in various towns in the country.

Table 7 indicates that Kota Kinabalu, Bayan Lepas and George Town receive the highest level of solar radiation in Malaysia. According to the head of the Renewable Energy Unit, PTM, Penang and Sabah are the best two spots to produce electricity from sunlight [19].

4. Solar energy applications in Malaysia

In Malaysia, the solar energy applications can be divided into two main categories: solar thermal application and photovoltaic (PV) technologies. Solar thermal is a technology where the heat from solar energy is harnessed for heating purposes while photovoltaic is a technology where arrays of cells which contain solar photovoltaic material convert the solar radiation into direct current electricity [19].

Table 7
Solar radiation in Malaysia (average value throughout the year).

Irradiance	Yearly average value (kWh/m^2)
Kuching	1470
Bandar Baru Bangi	1487
Kuala Lumpur	1571
Petaling Jaya	1571
Seremban	1572
Kuantan	1601
Johor Bahru	1625
Senai	1629
Kota Baru	1705
Kuala Terengganu	1714
Ipoh	1739
Taiping	1768
George Town	1785
Bayan Lepas	1809
Kota Kinabalu	1900

4.1. Solar thermal

Solar thermal consists of solar heating and cooling system such as Solar Water Heaters, solar pool heating, solar assisted drying system, solar space heating and cooling, ventilation, solar air conditioning and solar refrigerator [11].

The idea of harnessing solar energy for heating purposes is not new. Solar Water Heaters (SWHs) had successfully entered the global market commercially since 1800s [20]. Malaysia has a favourable climate for SWHs in household and commercial applications; due to lack of public awareness and SWHs initial high cost, Electric Water Heaters (EWHs) are more popular among Malaysian families due to easy installation and low price.

Malaysia has high solar energy potential with the daily average solar radiation of 4000–5000 Wh/m^2. The average sunshine duration was found to be in the range of 4–8 h/day. Therefore, Malaysia has favourable climatic conditions for the development of solar energy and SWHs for different economic sectors; however, many Malaysian families are still using EWHs. This is due to SWHs' high initial cost, less public understanding and awareness of the potential benefits of SWHs, and on the other hand inexpensive cost and easy installation of EWHs [21,22].

Due to inappropriate roof structures, some of the houses are not suitable for SWH installation in Malaysia. It may be assumed that about 1/5 of the residential buildings are not suitable for SWH systems due to the architectural constrains. Almost 1/3 of TNB's residential clients live in small villages across the country and they are unlikely to install SWHs. It is estimated that only 2,500,000 households are suitable for solar thermal collectors [23,24].

SWHs are also suitable for the commercial sector; however, most commercial businesses are located in urban areas and a potential for solar thermal applications depends on the type of business. Approximately 45,000 buildings can be considered for solar thermal. About 10% of them are not suitable due to shading or obstacles on the roofs [25,26].

The industrial sector is usually bordering the urban centres. They offer large roof areas (mainly flat roof) averaging 2000 m^2. Here, about 10% of the buildings are not suitable because of influencing factors (i.e. shading, and construction not able to carry additional weight).

About 110,000,000 m^2 of building surface area are available for different economic sectors for SWHs. This will provide about 75 GW of energy for the potential applications of SWHs [27].

In a study conducted in [28], comparing the annual cost between SWHs and EWHs in the long run, the installation of SWHs is more economical than installation of EWHs. The main reason is that cost of using EWHs will escalate due to the increasing electricity bill as a result of increase in family size [28] and possibly increases in the electricity tariff.

In Malaysia, generally there are 2 types of solar dryers. The Natural Convection Solar Dryers (passive dryers) which are simple, low power and short life span with low efficiency, and the Forced Convection Dryers (active dryers) which are more expensive with high power, long life span and high efficiency. On the other hand, solar dryers are categorized in 4 sub-classes which are direct solar dryers, indirect solar dryers, mixed-mode dryers and hybrid solar dryers. Hybrid systems include 6 types of solar dryers consisting:

(a) Solar drying system with thermal storage;
(b) Solar drying thermal with auxiliary unit (electric heating, biomass burner, LPG gas burner, solar drying system with diesel engine);
(c) Hybrid with geothermal or waste waters;
(d) Solar drying system with photovoltaic;
(e) Solar drying system with heat pump;
(f) Solar-assisted dehumidification system.

There are 4 main categories of solar assisted drying systems which are solar assisted drying system with the V-grove collector (used for drying chillies and green tea), solar assisted drying systems with the double pass collector (for oil palm fronds – an agricultural waste of the oil palm tree), solar drying system with photovoltaic thermal solar collector and solar assisted dehumidification system (for medicinal herbs) [29]. In Malaysia, the most common products used in solar drying system are from selected agricultural and marine products such as dried apple, banana, cashew nut in shells, cassava, cauliflower, chillies, copra, cocoa, coconut, figs, grapes, green peas, mango, onions, paddy, pineapple, rosella flower, strawberry, tea, tobacco, tomatoes, turmeric rhizomes, fish, oil palm and pegaga leaf [30].

Traditional refrigeration cycles contribute to depletion of ozone and hence impacting global warming. Due to the global warming, air-conditioning systems had become popular to control the temperature and humidity for indoor thermal comfort. There are 3 main categories in solar cooling systems: solar energy conversion system (also known as air-conditioning process for spaces which occurred at temperature of 8–15 °C, refrigeration system (for food, vaccine and storage at temperature of 0–8 °C) and cooling load (for ice-making or congelation purposes at temperatures below <0 °C) [31].

In solar refrigerator, the solar sorption refrigeration technologies are of concerned. Solar sorption is mainly based on the process of absorption liquid–gas and process of adsorption solid–gas [31]. However, the solar adsorption refrigeration technology is widely used and it may be classified as adsorbent–refrigerant combination used and system pressure. There are various combinations of the adsorbent and adsorbate pair in solar adsorption systems. For low pressure, the combination of Silica gel–water, Silica gel–methanol, Zeolite–water, and activated carbon–methanol are commonly used. Meanwhile, for high pressure, the combination of Silica gel–sulphur dioxide, Zeolite–flurocarbon, activated carbon–ammonia, and activated carbon–fluorocarbon are the most frequently used [32].

4.2. PV technologies

Photovoltaic technology was introduced in Malaysia in 1980s with the aim of providing electricity to rural areas (electrification and telecommunication), communication towers and consumer products. In 1998, Tenaga Nasional Berhad (TNB) started to set up grid-connected PV systems as the initiative for national power utility which was inspired by the success of the German Rooftop and Japanese Sunshine programmes. During 1998–2002, six pilot grid-connected PV systems were installed with power capacity ranging from 2.8 kWp to 3.8 kWp. The first practical experience of grid-connected PV system in July 1998 was relatively simple, basic but very expensive. It was installed by Tenaga National Research (TNR) Sdn. Bhd. on the rooftop of College of Engineering, University Tenaga Nasional (UNITEN) with the system capacity of 3.15 kWp. During the same year, two grid-connected photovoltaic systems were installed. One of them was installed at a BP petrol station along the KESAS highway with the capacity of 8 kWp by BP Malaysia while the other one was installed at Solar Energy Research Park in University Kebangsaan Malaysia (UKM) with the system capacity of 5.5 kWp [33,34].

Malaysia took on the challenge of designing energy efficient buildings by taking the initiatives to introduce energy savings in construction and design of high rise buildings in improving the air flow as well as using solar energy in the lighting system and heating requirements [35,36].

In October 1999, TNB research had built a single storey house PV installation with capacity of 3.6 kWp. To further prove the feasibility of PV integrated in roof design, in 2002, Prototype Solar House (PSH) projects were built near Kuala Lumpur as a part of an Industry Research and Development Grant Scheme (IGS) project. These projects were funded by Ministry of Science, Technology And Environment (MOSTE) of Malaysia (currently MOSTI) through the IGS. Implementations of these projects are through the joint-venture between NLCC architects of Malaysia and Fraunhofer ISE Germany. PSH has been designed and built in order to emphasize the multi-functional aspects of PV in buildings for living house at urban areas in the country [34,37].

In 2000, the first Malaysian Building Integrated Photovoltaic (BIPV) system was installed at a TNB senior officer's house located in Port Dickson with the capacity of 3.15 kWp. By November 2000, another BIPV system was installed in Shah Alam with a capacity of 3.24 kWp. In the following year, November 2001, another BIPV system was installed in Subang Jaya with the capacity of 2.8 kWp. The installations, being a standalone system, were fixed on the top of existing roof tiles and appeared to be successful since it is functioning without any problem in maintenance of the unit [33,34].

In 2005, total installed capacity of on-grid PV systems was around 470 kWp, whereas for off-grid PV systems were about 3 MWp. According to the Malaysian government in the 9th Malaysia Plan (9MP), a large amount of money had been allocated for the implementation of solar PV system especially in Sabah and Sarawak. On 25th July 2005, a Malaysian Building Integrated Photovoltaic (MBIPV) project had been announced and it is planned to end by 2010. The project consists of three categories which include: BIPV demonstration, national "SURIA1000" and BIPV showcase [38].

The main purpose of BIPV demonstration projects is to stimulate the local building industry, both the private and government sectors. The aim in SURIA1000 project is to install solar systems to 1000 roofs by 2010 and act as a catalyst for BIPV market. BIPV showcase target is for the general public and property developers to install BIPV at their premises, for example, homes and buildings. All of these MBIPV installations are being monitored by Photovoltaic Monitoring Schemes (PVMC) which is located at University Technology MARA (UiTM) under Global and Analytical Monitoring Schemes. Table 10 is a summary of the PV modules installed in MBIPV project [38,39].

Currently, there is a cumulative total of 213.61 kWp of BIPV systems installed and commissioned in Malaysia. MBIPV is a catalyst for the government to enhance the exposure of knowledge in

Table 8
Summary of PV modules installed in MBIPV project [39].

No.	Site name	PV capacity (kWp)	Type of PV cell	Inverter capacity (kW)	Inverter type
1	CETDEM, Petaling Jaya	0.90	Mono	0.7	SMA SB700
2	Tasik Kesuma Semenyih	5.25	Mono	6.0	Solarmax 6000E
3	Bukit Sebukor, Melaka	4.20	Mono	4.2	Solarmax 4200C
4	Private Bungalow, Taman Desa, Cheras	4.20	Mono	4.0	Fronius IG40
5	Setia Eco Park				Fronius
	i. Bungalow Z1A	5.775	Mono	5.775	IG60
	ii. Bungalow Z1B	5.28	Mono	5.28	IG60
	iii. Bungalow Z1C	4.2	Mono	4.2	IG40
	iv. Bungalow Z1D	5.445	Mono	5.445	IG60
	v. Bungalow Z1E	5.445	Mono	5.445	IG60
	vi. Bungalow Z2	5.445	Mono	5.445	IG60
6	Precinct 16, Putrajaya				Fronius
	i. Bungalow Z1	5.25	Mono	6.0	IG60
	ii. Bungalow Z2	5.40	Mono	4.0	IG40
	iii. Bungalow Z3	5.40	Mono	4.0	IG40
	iv. Bungalow Z4	4.32	Mono	4.0	IG40
7	PTM ZEO				Fronius
	i. Pack A1	45.36	Poly	50	IG500
	ii. Pack A2	1.92	Poly	1.5	IG15
	iii. Pack B	6.08	Thin film	6.0	IG60
	iv. Pack C1	5.824	Thin film	6.0	IG60
	v. Pack C2	5.824	Mono	6.0	IG60
	vi. Pack D	27.00	Mono	30.0	IG300
8	Putrajaya Perdana HQ	11.88	Poly	3.0×4 nos	Fronius IG30
9	Taman Kolam Air, JB	3.78	Poly	4.0	Fronius IG40
10	COOLTEK, Ayer Keroh	4.80	Poly	5.0	SMA SMC5000A
11	Private House, Bangsar	3.06	Poly	3.0	SMA SB3000
12	Private Bungalow, Bangsar	4.80	Poly	5.0	SMA SMC5000A
13	Show Unit House, Sungai Buloh	3.06	Poly	NA	NA
14	Private Bungalow, Puchong	4.80	Poly	NA	NA
15	SMK (P) Sri Aman	4.40	Poly	4.2	Solarmax 4200C
16	Country Height Damansara	4.00	Thin film	4.0	Fronius IG40
17	Private House, Taman United, Kuala Lumpur	3.15	Thin film	4.0	Fronius IG40
18	Monash University, Sunway				
	i. Pack 1	5.12	Thin film	4.2	Solarmax 4200C
	ii. Pack 2	2.24	Thin film	2.0	Solarmax 4200C
	Total	213.61			

application of solar technology in the country and place Malaysia on the world map as one of the countries promoting solar energy. Indeed, Malaysia has been approved as a member of the International Energy Agency-Photovoltaic Power Systems (IEA-PVPS) division. The idea of the technology used is basically either retrofit or integrated for residential homes, commercial buildings, universities and schools [40,41].

Some of the successful examples of energy efficient buildings in Malaysia are Kuala Lumpur Securities Commission located at Bukit Kiara, Kuala Lumpur, Ministry of Energy, Communication and Multimedia (MECM) located at Putrajaya and Pusat Tenaga Malaysia located at Bangi. Examples of energy efficient buildings show the shifting policy of the Malaysian government to use naturally available sources of energy in the construction sector to provide modern workplaces for future buildings in Malaysia [42].

In designing energy saving buildings, there is a need to conduct site analysis by studying the sun's path, the prevailing wind flow (if any), the surrounding terrain and taking advantage of the natural endowment to help reduce heat build-up onto the building material. This is the essential first step study required even before ever considering using any energy saving mechanical aids. The Ministry of Energy, Water and Communication (MEWC) building at Putra Jaya has achieved its standard benchmark of 135 kWh/m^2/yr, a standard set when its building was first constructed. The Malaysian Energy Centre Building has even exceeded its target by achieving 120 kWh/m^2/yr [35,39].

Malaysia has 2 sub-markets in solar power sector including stand-alone PV power system and on-grid PV power system. Stand-alone PV power system consists of off-grid domestic PV power system and off-grid non-domestic PV power system, while on-grid PV power system consists of grid-connected distributed PV power system and grid-connected centralized PV power system [19]. The total BIPV installed capacity by 2006 was 486 kWp with a total of 20 installations. The largest capacity was installed at the Enterprise Four Building at Technology Park Malaysia of 361.9 kWp which constitutes 74.5% of the total BIPV installed capacity. This installation indicates that Malaysia is capable of handling and managing large PV installations [34]. A summary of the cumulative installed PV power in 2007 and 2008 is shown in Table 8, while Table 9 shows the average price of PV power systems from 2005 until 2009.

Table 8 indicates total cumulative installed PV power increased from 7 MW to 8.8 MW, and Table 9 shows a decline in BIPV average

Table 9
The cumulative installed PV power in 31st December 2007 and 2008 (kW) [33].

Sub-market	2007	2008
Stand-alone domestic		
Stand-alone non-domestic	6.375	8.000
Grid-connected distributed	640,48	775,73
Grid-connected centralised	Nil	
Total (kW)	7.015,48	8.775,73

Table 10
Malaysia average BIPV price/kWp (2005–2009) [10].

procurement date	RM/kWp
December 2005	31,410
April 2006	27,988
June 2006	27,550
October 2006	29,293
November 2006	29,167
March 2007	28,006
May 2007	29,628
June 2007	23,191
September 2007	26,067
October 2007	24,970
March 2008	26,753
April 2008	29,358
May 2008	22,401
September 2008	26,235
October 2008	26,044
December 2008	26,835
April 2009	25,391
July 2009	22,988
August 2009	24,110
October 2009	20,439

price of 1 kWp from 2005 to 2009. By comparing the year-to-year statistics for the month of October, the price decreased from RM 29,293/kWp (in 2006) to RM 24,970/kWp (in 2007). The price keep on decreasing from RM 26,044/kWp (in 2008) to RM 20,439 in October 2009, hence the price is expected to decline further in the future even though the set-up cost of PV power installation is still very high.

There are 4 kinds of solar panels available in Malaysian PV market: Mono-crystalline Silicon, Poly-crystalline Silicon, Copper-Indium-Diselenide (CIS) and Thin film Silicon (using Amorphous Silicon) [41].

A study undertaken by UKM experts found mono-crystalline silicon and poly-crystalline silicon perform the best result when they are under hot sun, whereas on cloudy days CIS and thin film silicon performed better. Table 11 shows the performance indices according to the 4 solar panel types. Figs. 5 and 6 illustrate the average module efficiency of each module and performance of each solar panel, respectively.

As expected, mono-crystalline silicon is the most efficient PV module followed by poly-crystalline silicon type. Crystalline silicon is well known for providing high cell efficiency compared to thin film technology. CIS compared to the amorphous silicon solar panel, has shown higher module efficiency. It was purposely designed to give higher efficiency since CIS solar cells, under the Standard Test Conditions (STC), demonstrate higher efficiency.

Three main factories in Malaysia concerning PV capital equipment production, cell manufacturing, panel manufacturing and installations of the system are First Solar, Q-Cells and Sun Power.

4.3. Hybrid installations in Malaysia

Rural loads in Malaysia are basically supplied by stand-alone diesel power stations; however, due to the high maintenance cost of diesel stations, it is not efficient. Renewable energy hybrid systems are the best alternative for generating electricity in isolated islands and remote areas. In addition, there are some criteria

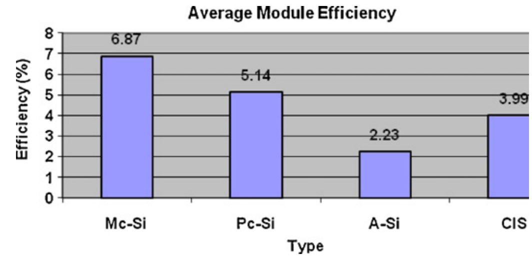


Fig. 5. Average module efficiency of solar module used in study [31].

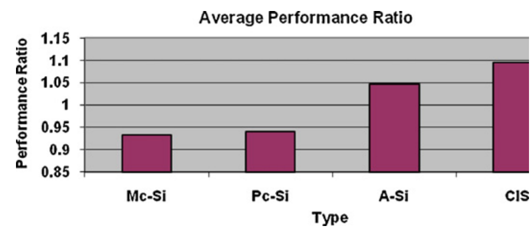


Fig. 6. Average performance ratio of each type of solar module [31].

such as resources availability, socio-economic situation, electricity demand, environmental impact, market-based and ability, payback period and willingness of the end users to pay for the electricity which must be considered in applying hybrid systems [43].

Basically, the Millennium Development Goals (MDGs) for rural electrification is to increase the country's Gross Domestic Product (GDP), while reducing poverty among communities and improving the development progress of the country's income, education, health, Information and Communication Technology (ICT), Bridging Digital Divide (BDD), environmental and security systems. Solar hybrid systems are also used in school-net projects to provide PC and internet connections; however, for rural schools, the PV and Very Small Aperture Terminal (VSAT) are powered by solar PV-diesel hybrid system. In 2007, it was reported by PTM that 4 kWp are installed per school with total estimated energy capacity of more than 1 MWp. For the island and rural electricity application of solar PV-diesel hybrid system, between 2006 and 2007, there were 7 projects with the capacity of 500 kWp [40].

In Pulau Perhentian Kecil, Terengganu, there are 2 wind turbines with 100 kW capacity each and 1 solar panel with 100 kW capacity. The total combined capacity is around 650 kW. Wind installation is basically for power generation and water pumping during the rainy seasons. Another example is Mersing Island, Johor Bahru, which was built in 2007 with a total capacity of 330 kW and monitored by TNB-Energy Services Sdn. Bhd. (TNBES). In Sabah, TNBES monitored 225 kW capacity and another 300 kW was monitored by Ministry of Education [44] where the application for 24 h electricity supply of 200 rural schools was approximately 17 kWp per school [40].

5. The prospect of solar energy in Malaysia

There are 5 major areas of research and development by universities in Malaysia including inverters, PV concentrators, solar

Table 11
Performance indices [40].

	Mono-crystalline Si	Poly-crystalline Si	Amorphous silicon	CIS
Measured value				
Average output efficiency (%)	30.1	30.34	33.74	35.31
Average module efficiency, η (%)	6.87	5.14	2.23	3.99
Performance ratio	0.933	0.941	1.046	1.094

cells fabrications and characterization, hybrid systems and energy conversion tracking systems. Research works undertaken by the local universities are developing grid-connected (3 kW) inverter by University of Malaya (UM), developing solar cell by University Science Malaysia (USM), developing organic cell by National University, developing (5 kW) grid-connected inverter and solar car by University Technology of Malaysia (UTM), developing a concentrator and PV systems by University Technology MARA (UiTM) and PV systems by TNB Research Sdn. Bhd. [45]. The major fund for the research in PV fields is mainly funded under the national science and techno funds by the Ministry of Science, Technology and Innovation (MOSTI).

Solar energy is not implemented in Small Renewable Energy Programme (SREP) mainly because of the high cost of PV cells and electricity tariff (21 cents/kWh). Greater effort has being undertaken to encourage the utilization of PV by supporting measures of direct capital subsidies to promote for cash rebate on a portion of grid-connected PV system costs. The government has also enhanced feed-in tariffs (FiTs) to encourage the greater use of RE including PV for power generation. Net metering, net billing and electricity utility activities are introduced for PV development by TNB. Furthermore, "Renewable Portfolio Standard" has been driven for the mandatory portion of grid-connected PV power where the power is purchased from grid-connected PV system owners. Tax incentives is also introduced to reduce or eliminate the purchase of PV systems, or as a simple way of definition, the deduction of total cost of portion of PV system cost from business or personal tax [16].

The government's tool for development of solar energy is the Malaysian Building Integrated Photovoltaic (MBIPV) Project. Currently, this MBIPV Project is targeting to emulate Germany's Renewable Energy Act (EEG feed-in tariff). Under the MBIPV project, SURIA1000 programme was introduced.

The SURIA 1000 programme is a financial incentive programme for the market which is based on Japan's Sunshine Project or also known as the Solar Photovoltaic Programme [45]. The programme is basically giving the average household or businessman to generate and sell the solar power to SESB or TNB with attractive returns. SURIA 1000 programme gives a capital discount or capital rebate up to 60% to encourage people to install solar panels but those who are interested have to bid for it though. Malaysia has undertaken policy drivers in promoting solar usage for electricity generation. The most impact driver would be feed-in tariffs (FiTs). It is basically a premium price for grid-connected PV electricity paid to system owners by utility or regulator body and the price is typically guaranteed for over 20 years. FiTs is the best tool to generate the fastest and lowest-cost deployment of renewable energy [46].

6. Conclusions

Malaysia has a strong potential to build large scale solar power due to its location at the equatorial region. The continuous supply of sunlight, silent in operation, low maintenance cost, independent of fuels source, the environmental friendly factors, and contributions to lower carbon emissions, made solar the best choice for future energy power generation. In Malaysia, more efforts in Research and Development (R&D) on solar energy are required in order to overcome the barriers to enhance the PV market in the country. One of the major barriers for solar energy is the economic barrier where the capital investment required is very high. With regard to the awareness and understanding of PV technology, educational programmes should be introduced not only at universities and college level, but also primary and secondary school level. In addition, to encourage rapid widespread of BIPV adoption, the media play an important role. Mass media should have special segment to focus more on solar technologies. In conclusion, a strong government policy on solar energy field is crucial to support PV market growth. A healthy competition among industry players and the new PV manufacturing industry must be promoted.

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